

Multi-Decadal Pathfinder Data Sets of Global Land Biophysical Variables from AVHRR and MODIS and their Use in GCM Studies of Biogeophysics and Biogeochemistry

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Project Goals, as Stated in 2000 NASA Proposal

This proposal was selected for investigation but de-scoped and limited to the first year of funding. The PI requested the funds to be distributed over a two year period to facilitate performance of the research by students who need at least two years to complete their graduate degree requirements. The research objectives of the descoped proposal, as per recommendation by the review panel, include (a) Scaling of 1 km AVHRR and MODIS look-up-tables to 5 km and 8 km resolutions by tuning the scaling parameters p_i and p_r ; (b) Validation of the biophysical product suite at various resolutions from data at the core sites, FIFE, BOREAS, and LBA, (c) Investigation of calibrations and comparisons between AVHRR, MODIS and SEAWIFS; (d) Analysis of 1 km AVHRR and MODIS surface reflectance data at the TERRA core validation sites in order to build the 1 km AVHRR look-up-table. Research objectives (a) and (b) was accomplished during the first funding period (June 2000 to May 2001). Our activities during Year 2 (June 2001 through May, 2002) have focused on the use of satellite derived land biophysical parameters in climate studies which include research tasks (c) and (d). Below, we provide a brief description of the research performed under this NASA support.

Accomplishments Under NASA Support for FY 2000-2002

A physically based technique for scaling with explicit spatial resolution dependent radiative transfer formulation has been developed

The problem of how the scale, or spatial resolution, of reflectance data impacts retrievals of vegetation leaf area index (LAI) and fraction absorbed photosynthetically active radiation (FPAR) has been investigated. We define the goal of scaling as the process by which it is established that LAI and FPAR values derived from coarse resolution sensor data equal the arithmetic average of values derived independently from fine resolution sensor data. The increasing probability of land cover mixtures with decreasing resolution is defined as heterogeneity, which is a key concept in scaling studies. The effect of pixel heterogeneity on

spectral reflectances and LAI/FPAR retrievals is investigated with 1 km Advanced Very High Resolution Radiometer (AVHRR) data aggregated to different coarse spatial resolutions. It is shown that LAI retrieval errors at coarse resolution are inversely related to the proportion of the dominant land cover in such pixel. Further, large errors in LAI retrievals are incurred when forests are minority biomes in non-forest pixels compared to when forest biomes are mixed with one another, and vice-versa. A physically based technique for scaling with explicit spatial resolution dependent radiative transfer formulation is developed. The successful application of this theory to scaling LAI retrievals from AVHRR data of different resolutions is demonstrated (Figure 1). This research is described in Tian et al. (2002).

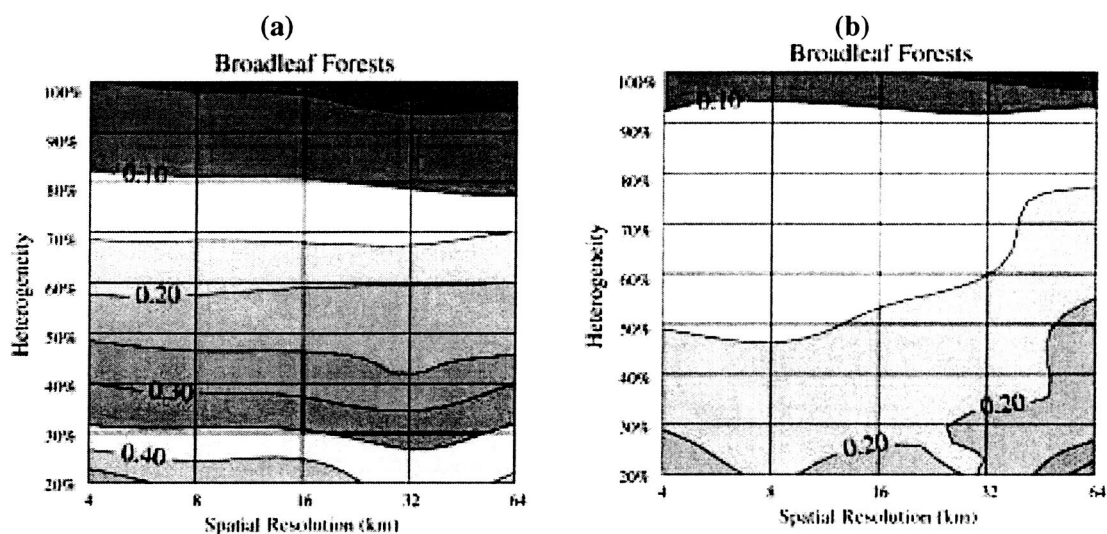


Figure 1. Counter plots of uncertainty in LAI derived from (a) unadjusted and (b) adjusted LAI retrieval algorithms as a function of spatial resolution and pixel heterogeneity. The heterogeneity is defined as the percent occupation of the dominant biome type within the pixel. Pixels with low heterogeneity value are more heterogeneous than those having high values. Note significant improvements in LAI retrievals in all cases, including the case of large pixels with significant heterogeneity. Tuning of the Look-up-Tables by adjusting the scaling parameters p_i and p_r to minimize uncertainties in LAI/FPAR retrievals constitutes the radiative transfer based approach to adjust the MODIS LAI/FPAR algorithm to retrieve biophysical parameters from data acquired by spectroradiometers of different spectral bands and different resolutions. Land surface reflectances at 1 km resolution from AVHRR over North America for July 1995 aggregated to different coarse scale resolutions were used in this example.

Analysis of a multi-year global vegetation leaf area index data set has been performed

The analysis of a global data set of monthly leaf area index (LAI), derived from satellite observations of normalized difference vegetation index (NDVI) for the period July 1981 to September 1994, is addressed in this effort. Validation of this retroactive coarse resolution (8 km) global multi-year data set is a challenging task because repeatative ground measurements from all representative vegetation types are not available. Therefore, the magnitudes and interannual variations in the derived LAI fields were assessed as follows. First, the use of NDVI-based algorithm, as opposed to a more physically based approach, is estimated to result in relative errors in LAI of about 10-20%, which is comparable to the mean uncertainty of AVHRR NDVI data. Second, the satellite LAI values compared reasonably well to ground measurements from three field campaigns (FIFE, BOREAS and OTTER, Figure 2). Third, when compared to

an existing multi-year LAI data set, a consistent discrepancy was noted between the two data sets. Fourth, interannual variations in LAI were evaluated through correlations with climate data sets, e.g., sea surface temperatures and precipitation in tropical semi-arid regions known for ENSO impacts, temperature dependence of vegetation growth in the northern latitudes. The general consistency between these independent data sets imbues confidence in the LAI data set, at least for use in large scale modelling studies. This research is described in Buermann et al. (2002).

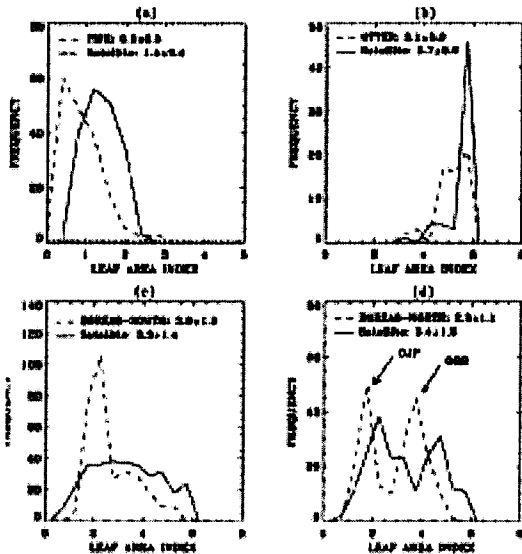


Figure 2. Comparison of field (dashed line) and 8 km satellite LAI (solid line) values for grasses and needleleaf forests. (a) FIFE (July 1987; 180 measurements), (b) OTTER (August 1990; 59 measurements), (c) BOREAS Southern Study Area (June 1994; 300 measurements) and (d) BOREAS Northern Study Area (June 1994; 200 measurements). The satellite LAI values are from 38.30°–39.70°N and 95.75°–97.25°W (FIFE), 44.40°–44.90°N and 122.10°–123.80°W (OTTER), 53.00°–54.50°N and 104.00°–106.50°W (BOREAS-SSA) and 55.00°–57.00°N and 96.50°–99.50°W (BOREAS-NSA), respectively.

Utility of satellite-based vegetation leaf area index data for climate simulations has been evaluated

The utility of satellite-based LAI data in improving the simulation of near-surface climate with NCAR CCM3 global climate model has been evaluated. The use of mean LAI values, obtained from the AVHRR Pathfinder data for the 1980s, leads to notable warming and decreased precipitation over large parts of the northern hemisphere lands during the boreal summer. Such warming and decreased rainfall reduces discrepancies between the simulated and observed near-surface temperature and precipitation fields (Figure 3). We also investigate the impact of interannual vegetation extremes observed during the 1980s on near-surface climate by utilizing the maximum and minimum LAI values from the 10-year LAI record. Surface energy budget analysis indicates that the dominant impact of interannual LAI variations is modification of the partitioning of net radiant energy between latent and sensible heat fluxes brought about through changes in the proportion of energy absorbed by the vegetation canopy and the underlying ground, and not due to surface albedo changes. The enhanced latent heat activity in the greener scenario leads to an annual cooling of the earth land surface of about 0.3°C, accompanied by an increase in precipitation of 0.04 mm/d. The tropical evergreen forests and temperate grasslands contribute most to this cooling and increased rainfall. This research is described in Buermann et al. (2001).

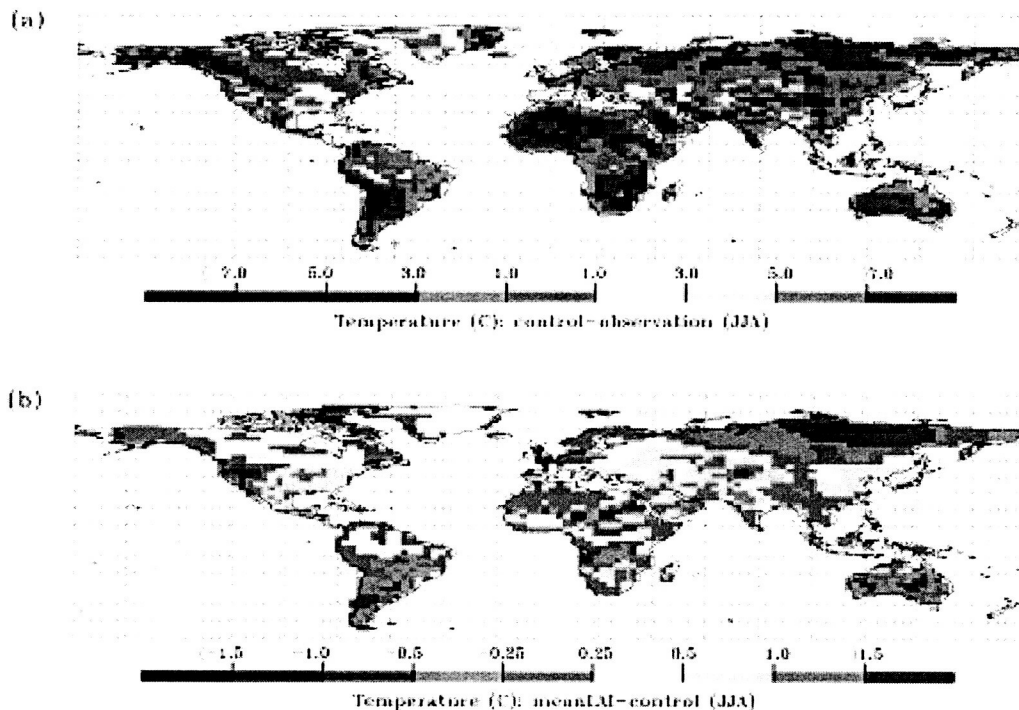


Figure 3. Information on realistic satellite-derived global LAI can improve the simulation of near-surface climate. Two runs of NCAR CCM3 (<http://www.cgd.ucar.edu:80/cms/ccm3/>) global climate model were performed, using a default (prescribed) CCM3 LAI profile and a global LAI field derived from satellite data. Panel b: Difference between near-surface temperatures predicted based on the realistic satellite derived LAI field and the default LAI profile indicates a substantial warming during the boreal summer over large parts of the northern hemisphere lands. In particular, the prediction of the near-surface temperature over grasslands during the active growing season in both hemispheres has been improved. The use of satellite LAI reduced the model biases in near-surface temperature in comparison to observations (Panel a)

Interannual covariability in northern hemisphere temperatures and greenness has been investigated

Circulation Anomalies Explain Warming and Greening. In Buermann et al. (2002) we explored if there were any correlated spatial patterns of interannual variability in surface temperature and satellite greenness data records of the northern hemisphere during the past two decades (1981-1998). The results indicated that the spatial patterns of the dominant modes of interannual covariability in these variables are strongly linked to large scale circulation anomalies such as the El Niño Southern Oscillation (ENSO), Arctic Oscillation (AO) and the Atlantic Tripole (AT). The two highest correlated spatial patterns representing the ENSO and AO teleconnection signals account for about 30% of spring temperature variability and 24% of spring NDVI variability (Figs. 4 and 5). Thus we were able to establish a dynamical connection between northern hemisphere greening and large-scale circulation anomalies via the anomalous warming of the past two decades.

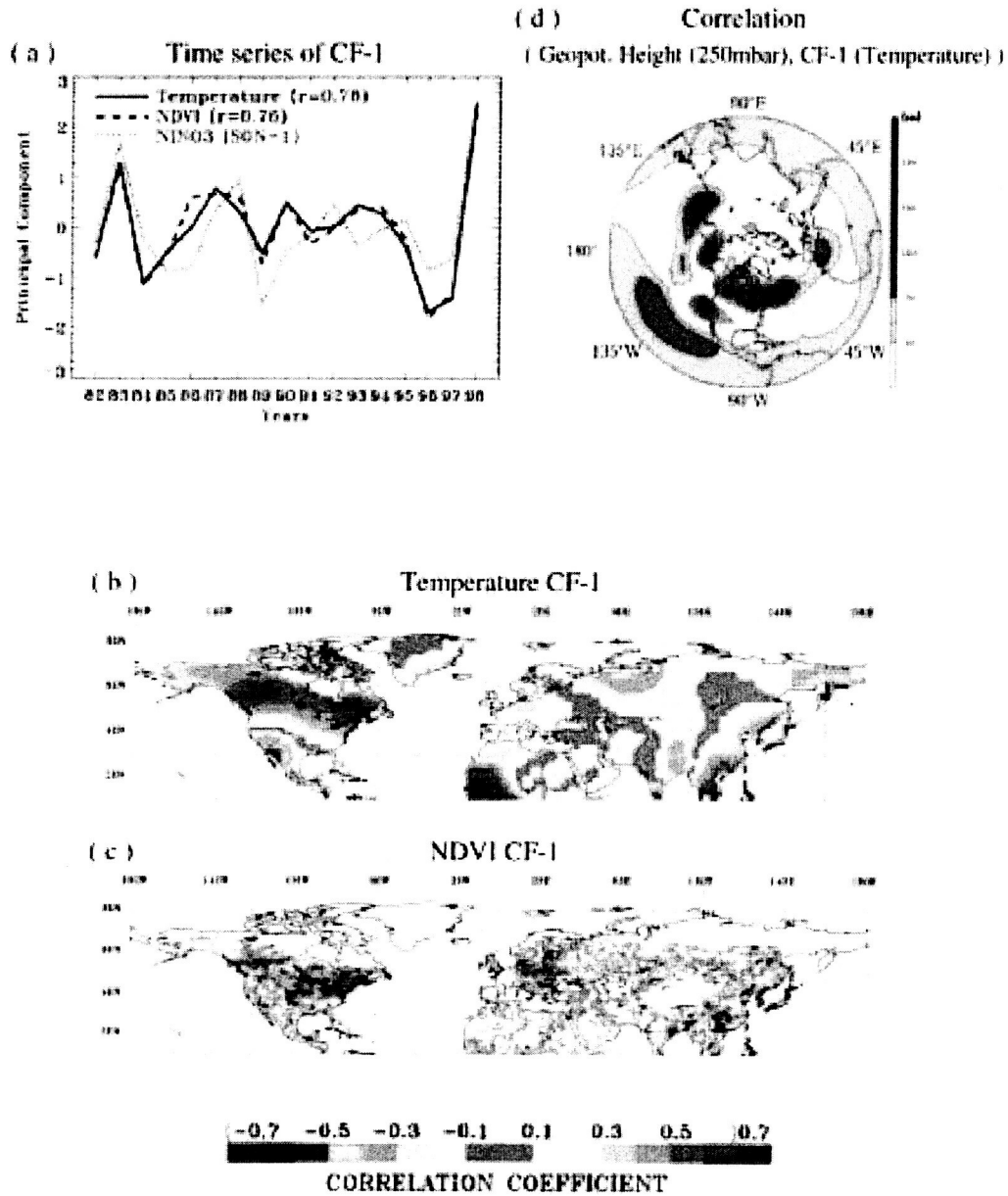


Figure 4. Panel a: Normalized time series of the first canonical factor (CF-1) of spring northern hemisphere (10N-90N) land surface temperature and NDVI anomalies for the 17 year period of record, 1982 to 1998. The standardized September through November average NINO3 index time series is also shown in this plot (red dotted line). The corresponding spatial patterns of correlation between the time series of the respective canonical factors and the data are shown in panels (b) for temperature and (c) for NDVI. Panel d: Correlations between spring 250 mbar geopotential height anomalies and the first temporal canonical factor of spring land surface temperature anomalies for 1982 to 1998.

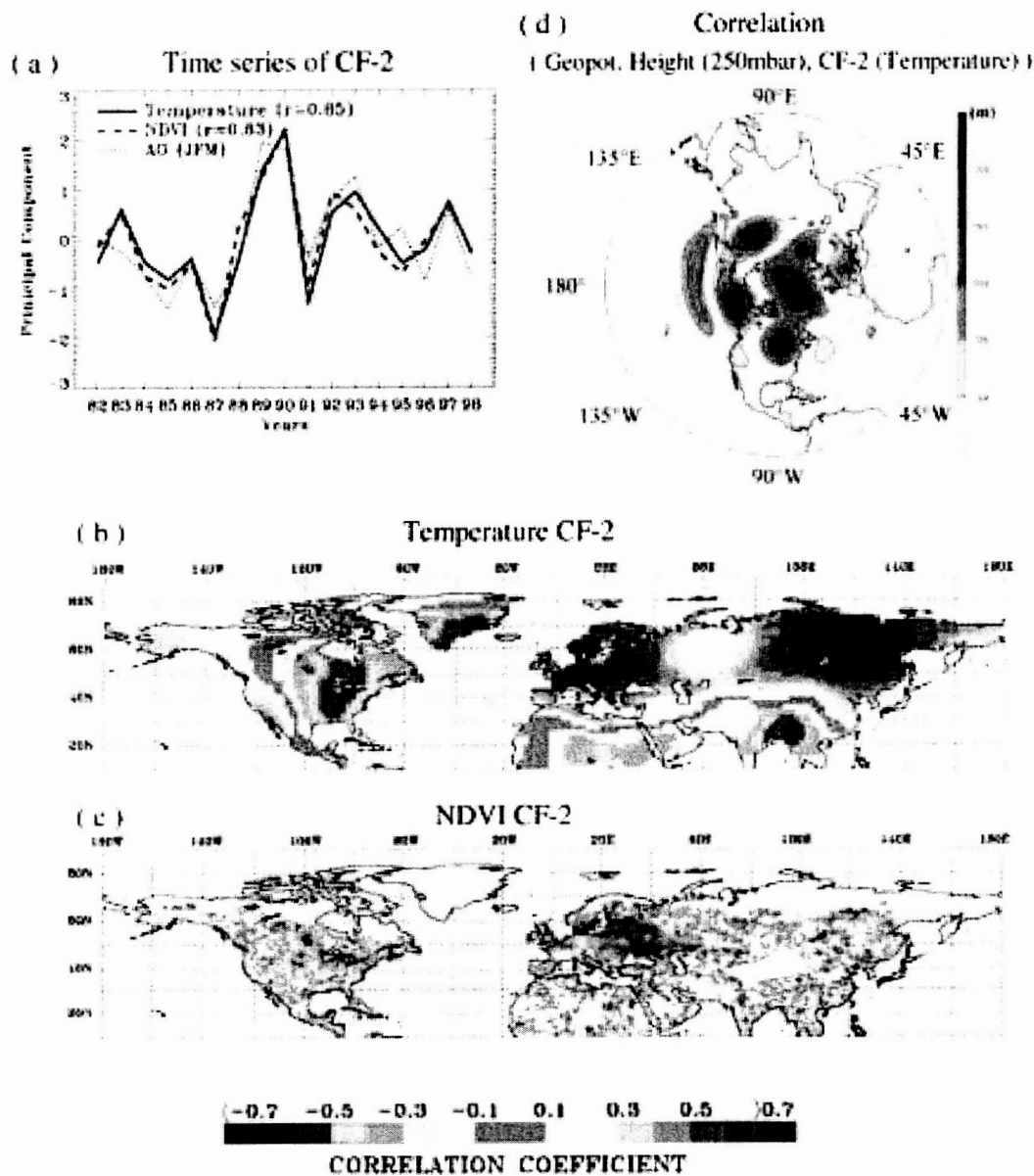


Figure 5. Panel a: Normalized time series of the second canonical factor (CF-2) of spring northern hemisphere (10N-90N) land surface temperature and NDVI anomalies for the 17 year period of record, 1982 to 1998. The standardized January through March average Arctic Oscillation (AO) index time series is also shown in this plot (red dotted line). The corresponding spatial patterns of correlation between the time series of the respective canonical factors and the data are shown in panels (b) for temperature and (c) for NDVI. Panel d: Correlations between spring 250 mbar geopotential height anomalies and the second temporal canonical factor of spring land surface temperature anomalies for 1982 to 1998.

Relation between interannual variations in satellite measures of vegetation greenness and climate has been analyzed

The relation between satellite-based measures of vegetation greenness and climate by land cover type at a regional scale ($2^\circ \times 2^\circ$ grid boxes) between 1982 and 1999 has been analyzed. We use the normalized difference vegetation index (NDVI) from the Global Inventory Monitoring and Modeling Studies (GIMMS) data set to quantify climate-induced changes in terrestrial vegetation. Climatic conditions are represented with monthly data for land surface air temperature and precipitation. The relation between NDVI and the climate variables is represented using a quadratic specification, which is consistent with the notion of a physiological optimum. The effects of spatial heterogeneity and unobserved variables are estimated with specifications and statistical techniques that allow coefficients to vary among grid boxes. Using this methodology, we are able to estimate statistically meaningful relations between NDVI and climate during spring, summer, and autumn for forests between 40°N and 70°N in North America and Eurasia. Of the variables examined, changes in temperature account for the largest fraction of the change in NDVI between the early 1980s and the late 1990s (Figure 6). Changes in stratospheric aerosol optical depth and precipitation have a smaller effect, while artifacts associated with variations in solar zenith angle are negligible. These results indicate that temperature changes between the early 1980s and the late 1990s are responsible for much of the observed increase in satellite measures of northern forest greenness (Zhou et al., 2003).

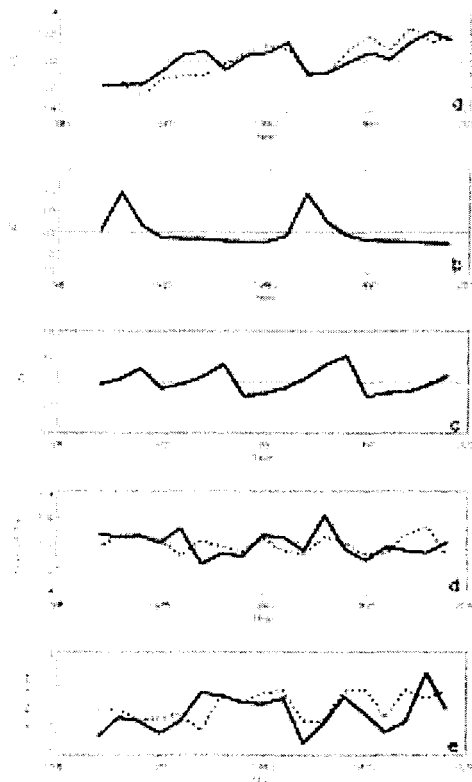


Figure 6. Spatial average of (a) NDVI, (b) Stratospheric aerosol Optical Depth (AOD), (c) Solar zenith Angle (SZA), (d) precipitation, and (e) temperature for vegetated pixels between 40°N and 70°N from 1982 to 1999 in North America (solid line) and Eurasia (dashed line).

Publications

- Buermann, W., Anderson, B., Tucker, C.J., Dickinson, R.E., Lucht, W., Potter, C.S., & Myneni, R.B., (2003). Circulation anomalies explain interannual covariability in northern hemisphere temperatures and greenness. *J. Geophys. Res.* (in press, accepted Dec 2002).
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- Zhou, L., Kaufmann, R. K., Tian, Y., Myneni, R.B., and Tucker, C. J. (2003). Relation between interannual variations in satellite measures of vegetation greenness and climate between 1982 and 1999. *J. Geophys. Res.* 108 (D1), doi:10.1029/2002JD002510.